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Sustainable Intensification of Rice-Fallow Areas through Strategic Crop Selection and Fertilizer Management in Lower Indo-Gangetic Plains

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ABSTRACT

In rainfed lowland rice ecosystem of eastern part of India, farmers generally sow various winter crops like lentil, lathyrus, chickpea field pea and linseed in the standing rice crop field just before the harvest of crop in order to utilize the post harvest soil moisture and nutrients. In this experiment the performance of *utera* crops was studied with fertilizers applied both in soil and foliar under rainfed rice ecosystem. The experiment was conducted with 3-main plot treatments consisting 3 *utera* crops viz. linseed, lentil and lathyrus; and 3 sub-plot treatments of fertilizer management viz. Suphala (NPK15:15:15) @ 150 kg ha^{-1} (22.5 kgNha^{-1}), Di-ammonium phosphate (DAP: NP18:46) @ 125 kg ha^{-1} (22.5 kg N) applied on saturated rice soil as basal 4 days before seed sowing of *utera* crops and DAP spraying@ 2 g/lit of water at 20,40 and 60 days after sowing respectively.The results of experiment in the lowland rainfed rice ecosystem revealed that legumes crops like lathyrus and lentil recorded the higher yields than linseed *utera* crops. In the experiment, soil application of suphala (NPK15:15:15) @ 150 kg ha^{-1} gave the highest grain yield followed by DAP soil application; DAP foliar spray recorded least.The variation in crop growth and yield attributes of *utera* crops were also similar to the trends as noted in crop yields. The variation in built up soil fertility was noted by the *utera* crops specially legumes. The actual ET of utera crops were veried being the lowest ETa, whereas, linseed had maximum ETa value. Crop water use efficiency value was more in lathyrus and with suphala but least value was noted in linseed crop and with DAP foliar spray.The maximum benefit-cost ratio was obtained in lentil and DAP soil application. Based on the results of experiment, lathyrus, lentil and linseed may be grown as *utera* crops with the soil application of complex fertilizer suphala (NPK15:15:15) @ 150 kg ha^{-1}in low land rice ecosystem of lower Indo-Gangetic Plains.

1 | INTRODUCTION

The 'Rice-fallow' term is used for rainfed *kharif* rice areas, which remain fallow or uncropped during the *rabi* season due to various abiotic and biotic constraints (Kumar *et al*., 2020). Rainfed rice agro-ecosystems play a crucial role in food production, and there is a significant opportunity to utilize residual moisture in rice-fallow areas to cultivate short-duration, low-input, and demanding pulse and oilseed crops. However, the success of crops grown on rice fallows largely depends on the method and cultivars of rice adopted (Kumar *et al.,* 2025). Rice-fallows extend over a large area (~22.3 million ha) in South Asia, with around 88.3% (~19.6 million ha) in India alone. In India, rice is cultivated on ~43.3 million hectares (Kumar *et al.,* 2018; Kumar *et al.*, 2021). On average, ~11.7 million hectares of *kharif* rice area remain fallow during consecutive *rabi* seasons due to various constraints in the country (Kumar *et al*., 2022; Srivastava *et al.,* 2023). Rice fields are scattered in the central regions, eastern plains, coastal peninsula, and northeast hills. The rice-fallow area under eastern India covers ~82% of the area alone, in states of Uttar Pradesh (0.35m ha), Jharkhand and Bihar (2.20 m ha), West Bengal (1.72 m ha), Odisha (1.22 m ha), Madhya Pradesh and Chhattisgarh (4.3 m ha), and Assam (0.54 m ha). Rice-fallow is the *kharif* (wet season) rice land that remains fallow during *rabi* (dry season). Rice is the principal crop during the *kharif* season in eastern India, occupying 26.8

million hectares, which accounts for 63.3 percent of the country's total rice-growing areas (Mahapatra *et al.,* 2022). Thus, India should focus on producing more food to meet its growing needs by increasing rice yields during the wet monsoon season, from June to October, and bringing more area (rice-fallow) under pulse or oilseed cultivation during the dry post-monsoon season, from November to April (Peramaiyan *et al.,* 2023). The moisture status of *aman* rice leaves an excellent scope for taking up another crop in *rabi* in low-land situations. Sometimes, farmers in the area grow *utera* crops during the post-rainy season, utilizing the in-situ soil moisture. In rainfed agriculture, water availability is the primary factor controlling crop productivity in rice-fallow systems. However, the growing of relay crops in rice-fallow systems during the post-rainy season has scope for utilizing carry-over soil water and residual soil fertility (Bandyopadhyay *et al*., 2016). There is a good scope for growing lentil, grass pea, oat, linseed, gram, and mustard as *paira* crops after the harvest of transplanted rice (Behera *et al*., 2020). The intensification of existing agricultural systems is a pressing need to meet the rising demand for food and ensure nutritional security in the country (Chowdhury *et al.,* 2020). In this respect, developing a sound land resource inventory (LRI) and its proper land use planning are on priority for rice-fallow areas in eastern India (Bandyopadhyay *et al*., 2019; Choudhary and Behera, 2019).

In West Bengal, farmers generally sow various winter crops, such as lentils, lathyrus, chickpeas, field peas, and linseed, in the standing rice crop field just before harvest, which helps ensure germination using the residual moisture. Among the abiotic factors, low soil moisture content and rapid soil moisture depletion frequently led to drought situations at flowering and harvesting. Even if the crop is managed well with residual soil moisture, short of winter rains at the grain-filling stage often lead to complete crop failures (Kumar *et al.,* 2018). Poor soil moisture and nutrient status are the primary limiting factors for the production of pulses and oilseeds in rice-fallow systems. Site-specific nutrient deficiencies (P, Zn, S, B, Mo), soil acidity, and low soil organic carbon (SOC) directly affect pulse and oilseed production in rice–fallow systems (Behera *et al*., 2020). Therefore, nutritional management for maximizing yield in pulses and oilseeds is a pressing need to address the malnutrition of people in developing countries. Since *paira* crops in relay cropping with rice suffer from nutritional stresses during the reproductive phase, late application of N is effective in reducing flower and pod drop in legume and in increasing seed yield (Singh and Satapathy, 2019). As soil moisture stress limits nodule formation by inhibiting the transport of carbohydrates from leaves to nodules, it is the perfect time to supply nitrogen and phosphorus to the legume plants at 40-50 days. The foliar application of 2% DAP significantly increased the seed yield in black gram, green gram, cowpea, and horse gram (Mahewari *et al.,* 2017). Foliar application of DAP is more effective than basal nitrogen and phosphorus fertilization because it supplies nutrients continuously over a more extended period, which may help photosynthates move steadily and increase crop yields (Sarkar *et al*., 2019). Therefore, there is a scope for Di-ammonium phosphate (DAP) and Suphala (NPK) complex fertilization in *utera* crops as top dressing in the mud soil in standing rice before harvest of the crop, or DAP foliar spray in the early growth period (20-50 days). The present experiment was conducted to investigate the response of *utera* crops to nutrient management in the lowland rice ecosystem of the lower Indo-Gangetic Plains in West Bengal.

HIGHLIGHTS

- Lathyrus (grass pea) and lentil legume crops showed potential for sustainable rice-fallow intensification.
- Soil application of Suphala (NPK 15:15:15) at 150 kg ha^{-1} produced the highest seed yield (650 kg ha^{-1}), outperforming DAP soil application (634 kg ha^{-1}) and DAP foliar spray (566 kg ha^{-1}).
- Lathyrus demonstrated superior water use efficiency (5.42 kg ha-mm^{-1}), while lentil with DAP soil application achieved the maximum benefit-cost ratio of 3.03, indicating both resources efficiency and economic profitability

2 | MATERIALS AND METHODS

A field experiment was conducted at the Agricultural Instructional Farm, Jaguli, Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal (22º56'N latitude, 88°32' E longitude, 9.75m above mean sea level) to study the performance of *utera* (no-till) crops as influenced by nutrient management in rice eco-system during *rabi* (winter) seasons of 2018-19 and 2019-20. The experimental site is located in a sub-tropical, sub-humid climate. The average rainfall is 1,450 mm, with 75% of it received between June and September. During the crop growth period, maximum temperature ranged between 23.34 °C and 33.99 °C, and minimum temperature varied between 9.97 °C and 18.04 °C (Table 1). The maximum relative humidity varied from 94.1% to 97.2%, and the minimum relative humidity varied from 44.9% to 59.6%. Total rainfall was distributed throughout the experimental period, but the highest rainfall was received in the month of November (44.3 mm), followed by December (26.8 mm).

The texture of the experimental topsoil was sandy clay loam (38-46:29-35:24-26%) and it belongs to the order Inceptisol with medium fertility and almost neutral soil pH (Table 2). The experiment was conducted on well-drained Gangetic alluvial soil. It was laid out in a split-plot design with three replications, featuring different utera crops in the main plots: C1-Linseed cv Neela, C2-Lentil cv Maitri, C3-Lathyrus cv Ratan, while different nutrient management treatments were applied in subplots, i.e., N1-Suphala (NPK 15:15:15) at 150 kg ha^{-1}, N2-DAP (NP 18:46) at 125 kg ha-1, N3-DAP spray (2% dilution) three times. The main plot size measured 12 m x 3 m, and the subplots 4.0 m x 3.0 m. Utera crops were sown in the first week (4th and 5th) of November in both 2018-19 and 2019-20. Seeds were sown with a higher seed rate (20% more), specifically 40 kg ha^{-1} for linseed, 80 kg ha^{-1} for lathyrus, and 40 kg ha^{-1} for lentil. Before sowing, seed priming was done with clean water for 6 hours, and seeds were broadcast in standing rice fields 10 days before rice harvesting when soils were sufficiently oversaturated. Soil application of complex Suphala and DAP (Di-ammonium Phosphate) fertilizers was made to the crop fields 4 days prior to seed broadcasting, when the rice field had a thin film of ponding water (1-2 mm). For the spray treatment of DAP @ 2% dilution (500 liters ha^{-1}), battery-powered sprayers were used three times at 20, 40, and 60 days after sowing. *Utera* crops received winter rains totaling 44.3 mm and 26.8 mm during early stages, but no rainfall occurred during flowering and maturity periods.

The crop was harvested when the plants turned yellowish to brown and had near-optimal seed moisture. After harvest, the crops were left in the field for 2-3 days to sun-dry. Then, the harvested bundles from each plot were taken to a clean threshing floor, where threshing was performed separately for each plot. Growth parameters such as plant height, dry matter accumulation (DMA), crop growth rate (CGR), primary and secondary branches per plant at flowering, and nodules per plant were recorded periodically at 30, 45, and 60 DAS, as well as at harvest. Yield components including plant population at harvest, number of pods per plant, seeds per pod, 10-pod weight, and test weight (1000-seed weight) were recorded at harvest. After threshing, seeds were sun-dried, cleaned, weighed, and converted to kg ha^{-1}. Stover yield was also estimated in kg $ha^{-1.}$ The residual effects of utera crops were assessed by analyzing the soil nutrient status after harvest, following standard methods.

The gravimetric method was used to determine the moisture content in the soil samples at depths of 15 and 30 cm. Soil samples for profile soil moisture status were taken at 15-days intervals from sowing to the harvest period. Soil moisture (SM) content was calculated using the equation below.

$$SM\ (\%) = \frac{\text{Weight of wet soil - Weight of dry soil}}{\text{Weight of dry soil}} \text{ X } 100$$

The total water expenditure in this study was calculated in terms of actual evapotrnaspiration (ETa), which was calculated as profile contribution (PC) plus ER (effective rainfall) as ETa (mm) = PC+ ER and

$$PC\ (mm) = \frac{SMh\text{-}SMi}{100} \text{ x BD x D}$$

Where, SMh- harvest soil moisture (%), SMi-initial soil moisture (%); BD-soil bulk density (g cc^{-1}), D-depth of soil profile (cm).

The water productivity of crops was calculated in terms of water use efficiency (WUE) as dividing the seed yield (Y) by actual evapotranspiration (ETa). Water use efficiency (WUE) was estimated as

$$WUE\ (kg\ ha\text{-}mm^{-1}) = \frac{Y\ (kg\ ha^{-1})}{ETa\ (mm)}$$

Where, Y-seed yield, ETa-Actual evapo transpiration.

The data collected on growth parameters, yield components, and yields were analyzed following the method of analysis for split-plot design as described by Gomez and Gomez (1984). The significance of different sources of variation was tested at a probability level of 0.05. The standard error of mean (SEM) and the value of CD were indicated in the tables to compare the difference between the mean values.

TABLE 1 Meteorological data during the experimental period 2018-19 and 2019-20 (mean)

Month	Temperature (^{0}C)		Relative humidity (%)		Total rainfall (mm)	Pan evaporation (mm day^{-1})	Bright Sunshine (hr)
	Max.	Min.	Max.	Min.			
November	29.48	14.76	96.96	59.56	44.3	2.03	7.77
December	32.48	10.41	96.61	57.06	26.8	1.40	5.78
January	23.34	9.97	97.19	51.80	0.0	1.55	8.85
February	29.45	12.99	97.21	46.10	0.0	2.22	12.05
March	33.99	18.04	94.06	44.93	0.0	3.93	6.59

Source: Department of Agricultural Meteorology and Physics, B.C.K.V., Mohanpur, Nadia

TABLE 2 Soil texture, bulk density, and saturated hydraulic conductivity in the soil profile of lowland rice-ecosystem

Soil layers (mm)	Textural group (%)			B.D (Mg m^{-3})	Saturated hydraulic conductivity (mm h^{-1})
	Sand	Silt	Clay		
0-150	46.14	24.25	29.61	1.41	4.6
151-300	38.23	26.32	35.54	1.46	1.8
301-450	32.13	29.19	38.68	1.51	1.5
451-600	45.32	23.42	31.26	1.48	2.8
601-1200	56.12	16.23	27.65	1.46	7.2

3 | RESULTS AND DISCUSSION

3.1 | Growth Attributes

Plant growth, measured by the plant height of *utera* crops, was significantly influenced by nutritional management practices. Among *utera* crops—linseed, lentil, and lathyrus—plant height increased consistently as the crops developed (Table 3). At harvest, plant heights of linseed, lentil, and lathyrus ranged from 45.0 to 61.9 cm, with linseed reaching the tallest height at 61.9 cm. In the experiment, utera crops fertilized with Suphala (NPK 15:15:15) achieved the highest plant height of 67.6 cm, followed by 56.4 cm, while DAP spray treatment resulted in the shortest height of 49.5 cm. Higher plant heights, with proper nutrition, indicated better internode elongation and improved vegetative growth throughout the crop cycle.

Total dry matter production increased gradually with the advancement of crop age and reached its peak at the time of crop harvest. Among the utera crops, linseed, lentil, and lathyrus, dry-matter accumulation increased progressively with the advancement of crop growth, and their variations were due to differences in crop nutrition.

At harvest, dry-matter production among utera crops, such as linseed, lentil, and lathyrus, varied from 209.9 to 288.8 g m^{-2}, with a 37.58% variation. The highest dry matter production (288.8 g m^{-2}) in lathyrus was recorded. In the experiment, *utera* crops fertilized with DAP foliar spray recorded highest dry matter production of 257.1g m^{-2} followed by DAP Soil (NP 18:46) 254.2 g $m^{-2,}$ and least value of dry matter production 243.8 g m^{-2} was recorded under Suphala (NPK 15:15:15). Application of foliar nutrition at later stage was helpful for plants to grow and produce higher amount dry-matters.

Dry-matter partitioning of crop growth over time in terms of crop growth rate (CGR) of utera crops was significantly affected by different nutrient management practices (Table 3). Although CGR was slow during the early initial stage (just after sowing), it then increased progressively with crop age up to the active vegetative and reproductive stages (Table 3). From 60 DAS to harvest, the CGR value of utera crops ranged from 2.03 to 3.18 g m-2 day-1, with a 56.65% variation, and the highest crop growth rate was observed in lathyrus (3.18 g m-2 day-1). In the experiment, utera crops fertilized with DAP (NP 18:46) recorded the highest CGR value at 3.32 g m-2 day-1, followed by Suphala (NPK 15:15:15) at 3.19 g m-2 day-1.

The production of branches in *utero* crops, such as linseed, lentil, and lathyrus, at flowering time varied significantly with variations in different nutritional management practices (Table 3). At flowering time, the number of primary branches of the crop varied from 6.3 to 8.4, with a 33.33% variation, and a larger number of branches (8.4) in the lentil crop and a smaller number of secondary branches (6.3) in the linseed were seen (Table 3). In the experiment, utera crops fertilized with Suphala recorded the largest number of secondary branches (7.5), followed by DAP-spray 7.3 and the smallest number of secondary branches (6.5) was recorded under DAP (NP 18:46).

The number of active nodules at the flowering stage of crop growth was significantly affected by different nutritional management practices (Table 3). Variations due to crop nutrition were observed from the initial flower stage to 50% flowering, but after flowering was complete, the nodule number continued to decline. Among the paira crops like lentil and lathyrus, the nodule numbers per plant at the flowering stage ranged from 24.8 to 26.0, with the higher number recorded in lathyrus (26.0). In the experiment, utera crops fertilized with DAP (NP18:46) had the highest number of nodules per plant (18.7), followed by Suphala (NPK 15:15:15) with 17.8, while the lowest was under DAP spray treatment with 14.3 nodules per plant. Similar effects of crop nutrition on the growth attributes of utera crops have been reported by Kumar *et al.*, 2023.

TABLE 3 Effect of fertilizer management on growth parameters of *utera* crops in rice-fallow (pooled data of two years)

Treatments	Plant height at harvest (cm)	TDM at harvest (gm^{-2})	CGR at 60-harvest (gm^{-2} day^{-1})	Branching at flowering	Nodule $plant^{-1}$ at flowering
***Utera* crop**					
Linseed	61.9	209.9	2.03	6.3	0.00
Lentil	45.0	256.4	2.32	8.4	24.8
Lathyrus	51.1	288.8	3.18	6.6	26.0
S.Em(±)	0.65	1.15	0.09	0.05	0.05
C.D (p=0.05)	2.42	4.63	0.37	0.21	0.19
Crop Nutrition					
Suphala	54.8	243.8	3.19	7.5	17.8
DAP Soil	53.8	254.2	3.32	6.5	18.7
DAP Spray	49.5	257.1	2.80	7.3	14.3
S.Em (±)	0.34	1.25	0.14	0.12	0.08
C.D (p=0.05)	1.07	3.59	0.44	0.39	0.23

TDM- Total dry matter; CGR- Crop growth rate

3.2 | Yield Attributes and Yield

Plant population at harvest, an important parameter in *utera* crops, was significantly influenced by nutrient management in lowland rice ecosystem (Table 4). The maximum plant population was 49.7 plants per m², and the minimum was 42.8 plants per m². Crop nutrition with DAP soil fertilizer in the *utera* crops had a distinctive impact on the population. The maximum plant population was observed with Suphala fertilizer management in the lathyrus crop. Pods plant^{-1}of *utera* crops like linseed, lentil and lathyrus in rice ecosystem was significantly influenced by nutrient management practices (Table 4). Among *utera* crops lentil recorded the highest number of pods plant^{-1} (27.1) followed by lathyrus (25.4) but linseed crop gave the lowest number of pods plant^{-1} (8.7). The *utera* crops fertilized with Suphala recorded the highest number of pods plant^{-1}(21.6), followed by DAP-soil (20.5), and a relatively smaller number of pods plant^{-1} (19.0) were recorded in DAP-spray. Kumar *et al. (*2023) reported similar impacts of fertilization on *utera* crops.

The number of seeds per pod of utera crops was also significantly affected by nutrient management practices (Table 4). Among these crops, linseed recorded the highest number of seeds per pod at 6.9, followed by lathyrus at 4.1, while lentil produced a significantly lower number of seeds per pod at 2.1. In the experiment, utera crops fertilized with Suphala recorded the highest number of seeds per pod (5.1), followed by DAP soil application treatment (4.2), with the lowest number recorded in DAP spray (3.9). Seeds per pod were also influenced by nutrient management. Linseed, a small-seeded oilseed crop, produced more seeds per pod than lathyrus and lentil. The 10-pod weight of utera crops such as linseed, lentil, and lathyrus in the rice ecosystem was significantly affected by nutrient management practices (Table 4). Among these, lentil recorded the highest 10-pod weight at 2.37 g, followed by lathyrus at 2.03 g, while linseed yielded significantly less at 0.55 g. In the experiment, utera crops fertilized with Suphala (NPK 15:15:15) recorded the highest 10-pod weight at 1.86 g, followed by DAP (NP 18:46) soil application, while the lowest was in DAP foliar spray treatment at 1.38 g. The plumpness or boldness of seeds, measured as test weight (1000 seed weight), was significantly affected by diversified nutrient management. Among these crops, lathyrus had the highest test weight at 59.1, followed by lentil at 20.9, while linseed had a very low test weight at 5.3. In the experiment, utera crops fertilized with Suphala (NPK 15:15:15) recorded the highest test weight at 30.2, followed by DAP (NP 18:46) treatment at 28.6, with DAP spray showing the lowest at 26.5. Many researchers have reported a positive response of nutrient management on the growth and yield attributes of utera crops (Maheswari *et al.*, 2017; Kumari et al., 2024; Saha *et al.*, 2025).

The land productivity, in terms of seed yield, of utera crops like linseed, lentil, and lathyrus grown in a rice ecosystem was significantly influenced by nutrient management practices (Table 4). Among the *utera* crops, lathyrus recorded the highest yield of 725 kg ha^{-1} followed by lentil (721 kg ha^{-1}), but linseed crop gave significantly less yield of 404 kg ha^{-1}. In harmony with our findings, Bandyopadhyay *et al*. (2018) also reported that a higher yield of lentil was obtained in the no tillage condition than in the conservation and minimum tillage conditions. The yield variation among the *utera* crops was 79.45%. In the experiment, *utera* crops fertilized with Suphala (NPK 15:15:15) @ 150 kg ha^{-1} recorded the highest grain yield (650 kg ha^{-1}), followed by DAP (NP 18:46) @ 125 kg ha^{-1}, and the lowest seed yield (565.83 kg ha^{-1}) was recorded in DAP foliar spray treatment. The yield variation due to differential nutrition was 14.85% which was much less under the zero-till situation. The availability of nutrients may have contributed to the increased translocation of photosynthates to the sink, resulting in improvements in yield attributes and crop yields of legume crops (Singh *et al*., 2018; Kumar *et al*., 2023).

The biomass productivity in terms of stover plus seed yield of *utera* crops like linseed, lentil and lathyrus in rice ecosystem was significantly influenced by the nutrient management practices (Table 4). Among the *utera* crops, lathyrus recorded the highest biomass yield of 2481 kg ha^{-1}

TABLE 4 Effect of fertilizer management on yield attributes and yield of *utera* crops in rice-fallow (pooled data of two years)

Treatments	Plant population at harvest	No of pods plant^{-1}	Seeds pod^{-1}	10 pod weight (g)	Text weight (g)	Seed yield (kg ha^{-1})	Biomass yield (kg ha^{-1})	Harvest Index
***Utera* crop**								
Linseed	42.8	8.7	6.9	0.55	5.3	404	1508	0.27
Lentil	49.0	27.1	2.1	2.37	20.9	721	1970	0.37
Lathyrus	49.7	25.4	4.0	2.03	59.1	725	2481	0.29
S.Em(±)	0.23	0.41	0.39	0.15	0.82	12.6	12.7	0.06
C.D (p=0.05)	0.63	1.15	1.10	0.44	2.69	37.17	37.73	0.19
Crop Nutrition								
Suphala	49.6	21.6	5.0	1.86	30.2	650	1910	0.29
DAP Soil	49.8	20.5	4.2	1.71	28.6	634	1965	0.25
DAP Spray	42.1	19.0	3.9	1.38	26.5	566	2084	0.26
S.Em(±)	0.21	0.61	0.14	0.10	0.35	15.56	8.47	0.08
C.D (p=0.05)	0.64	1.83	0.42	0.31	1.04	45.91	24.74	NS

followed by lentil (1970 kg ha^{-1}) but linseed crop gave very less biomass yield of 1508 kg ha^{-1}. In the experiment, *utera* crops fertilized with DAP foliar spray recorded the highest biomass yield (2084 kg ha^{-1}) followed by DAP (NP 18:46) the treatment (1965 kg ha^{-1}) and the lowest biomass yield (1909 kg ha^{-1}) was recorded in Suphala treatment. Source to sink ratio in terms of harvest index of *utera* crops like linseed, lentil and lathyrus in rice ecosystem was significantly influenced by nutrient management practices (Table 4). Among *utera* crops, lentil recorded the highest harvest index of 0.37 followed by lathyrus (0.29) but linseed crop gave very less harvest index of 0.27. *Utera* crops fertilized with Suphala (NPK 15:15:15) recorded the highest harvest index (0.29), followed by DAP spray treatment (0.26), and the lowest harvest index (0.25) was recorded in DAP (NP 18:46) treatment. Similar positive response of DAP has been reported by Suhathiya and Ravichandran (2018).

TABLE 5 Effect of fertilizer management on nutrient status in post-harvest soil of *utera* crops in rainfed rice-fallow (pooled data of two years)

Treatments	Nutrient status in post-harvest soil			
	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})	SOC (%)
Utera crop				
Linseed	190.2	28.8	194.0	0.56
Lentil	227.9	42.2	207.4	0.65
Lathyrus	225.5	38.7	200.2	0.63
S.Em(±)	1.91	1.14	5.80	0.10
C.D (p=0.05)	7.56	4.58	23.40	0.50
Crop Nutrition				
Suphala	216.8	35.2	228.5	0.62
DAP Soil	234.7	42.1	189.6	0.66
DAP Spray	192.2	32.5	183.6	0.61
S.Em(±)	2.93	1.42	4.34	0.12
C.D (p=0.05)	8.71	4.38	13.35	0.38
Initial Value*	156.8	25.0	146.8	0.60

*pH 7.61; Interactions - significant

3.3 | Nutrient Dynamics

The status of available N, P, K, and soil organic carbon (SOC) in soil was significantly affected by different nutrient management practices (Table 5). Among utera crops, linseed, lentil, and lathyrus, the results revealed that N, P, K, and organic carbon content differ significantly.

The data on the available nutrients in the soil after crop harvest are presented in Table 5. The status of available N, P, K, and SOC in soil was significantly influenced by different *utera* crops and nutrient regimes. The results were encouraging, as the N, P, and K contents increased significantly, regardless of the various crops and fertilizer regimes, compared to the initial value. The legume crops, such as lentil and lathyrus, also enhanced the organic carbon content. Maximum content of available nitrogen, phosphorus, potassium and organic carbon content was noted under lentil crop grown field i.e. (227.9 kg ha^{-1}, 42.3 kg ha^{-1}, 207.4 kg ha^{-1} and 0.65%) followed by lathyrus grown field i.e. (225.5 kg ha^{-1}, 38.8 kg ha^{-1}, 200.2 kg ha^{-1} and 0.63) but linseed grown field gave less available nutrient status i.e.(190.2 kg ha^{-1}, 28.8 kg ha^{-1}, 194.0 kg ha^{-1} and 0.56%). This might be attributed to the combined effects of legume N-fixation and applied fertilizer, which was utilized less in rainfed situations. Among the different nutrient management practices available, nitrogen, phosphorus, and % of organic carbon were found to be maximum in the plot fertilized with DAP (NP 18:46) soil application i.e., (234.7 kg ha^{-1}, 42.1 kg ha^{-1} and 0.66%) and potassium status was maximum in the plot fertilized with suphala (NPK 15:15:15) i.e. (228.5 kg ha^{-1}). The lowest nutrient status was observed under the DAP foliar spray treatment only. The larger increase in NPK status happened in lentil and lathyrus than in linseed. This was also true in carbon sequestration in lentil and lathyrus but organic carbon decreases in lentil *utera* crops. Similar findings on SOC and built-up soil fertility in utera crops in rice-fallow systems have been reported by Kumar *et al*. (2022).

3.4 | Soil Moisture Dynamics

Soil moisture extraction pattern of *utera* crops like linseed, lentil and lathyrus was very much influenced by crop nutrition sources (*Fig.1*). *Utera* crops were sown on saturated paddy soils in standing rice 10-days before harvest of crop. Fertilizers like Suphala and DAP were applied 4-days before seed sowing of crops. Soil moisture varied from 38.8 to 42.0% at the seed sowing stage, and at harvest, soil moisture varied from 17.6 to 18.3% at 0-15 cm soil depth, and at a lower depth of soil (15-30 cm), soil moisture was from 22.4 to 25.4% depending on the type of crops. The results of soil moisture variations corroborate the findings of Kumari *et al*. (2024).

Variation in actual evapotranspiration (ETa) of utera crops was greatly influenced in the no-till rice ecosystem (Table 6). The Lathyrus crop, with its extensive ground coverage, has the lowest ETa value (133.8 mm). In contrast, the linseed crop, characterized by deep roots and less ground cover, recorded the highest water uptake, showing an Eta value of 182.00mm. The variation in Eta

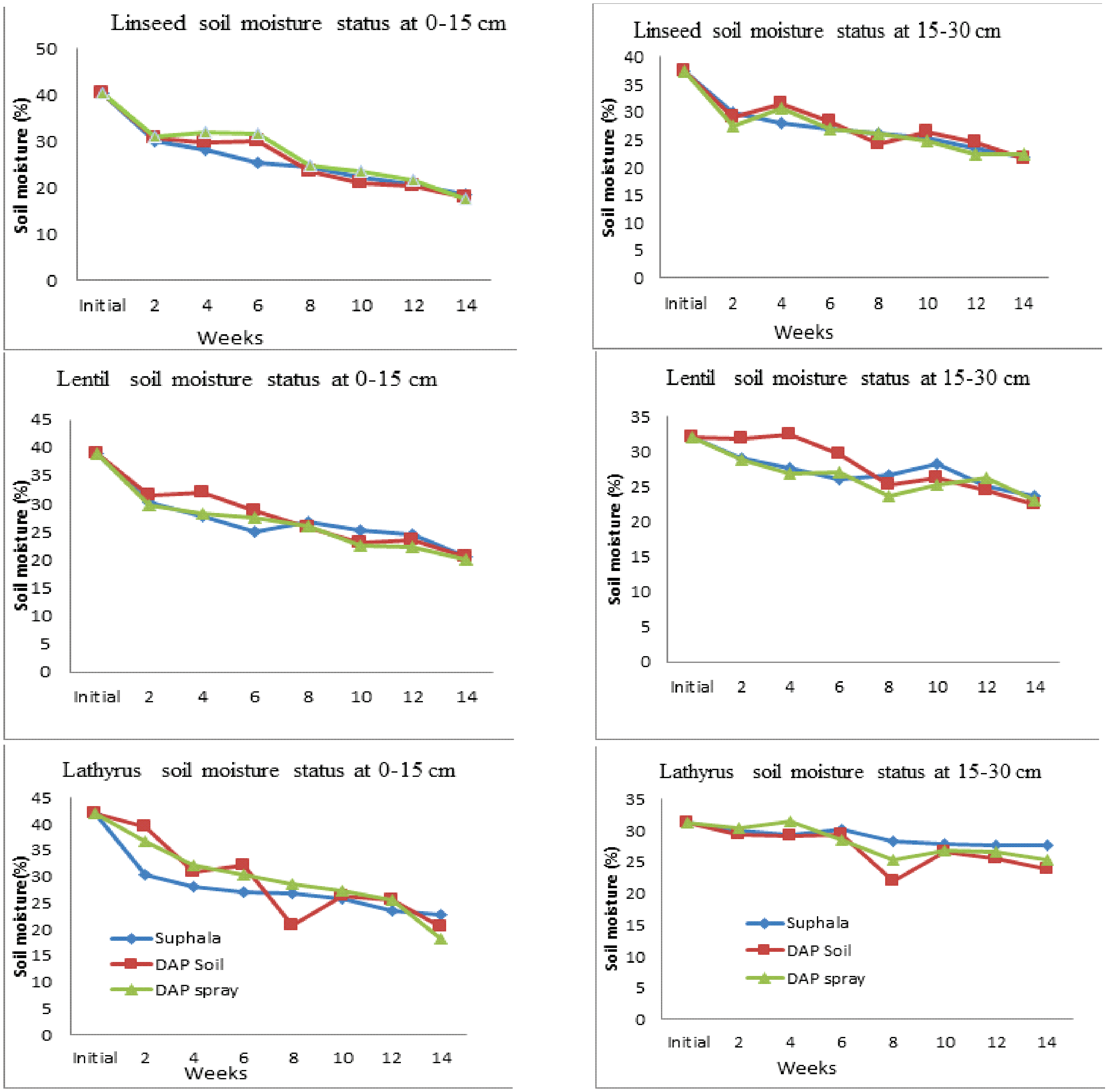

FIGURE 1 Soil depletion pattern at 0-15 and 15-30 cm soil depth as influenced by type of *utera* crops grown and fertilizer used

was 36.0%, which may be attributed to differences in canopy cover and water extraction. Fertilizer application of DAP soil registered the highest ETa value of 187.7 mm, followed by Suphala (156.5 mm), while the least ETa was observed in DAP spray. Here, the variation in ETa was up to 19.9%, likely caused by their nutrient mining capacity in *utera* cropping systems. In rainfed rice-fallows, ETa is influenced by profile moisture and rainfall, which affect crop water productivity in utera crops (Bandopadhyay *et al.,* 2016).

Water use efficiency (WUE) of utera crops like linseed, lentil, and lathyrus in rice ecosystems was much influenced by nutrient management practices (Table 6). The WUE of linseed, variety Neela, recorded 2.42 kg ha-mm^{-1}, while the highest WUE was achieved by Lathyrus at 5.42 kg ha-mm^{-1}, with a variation of more than double (124.2%) in no-till rice ecosystems. This wide variation may be due to the smothering habit of lathyrus, which helped conserve soil moisture by reducing evaporation. Differences in nutrient feeding among utera crops resulted in a narrower variation (16.9%) in WUE values. Among fertilizer sources, Suphala proved to be the most effective, followed by DAP foliar spray based on WUE. The DAP foliar spray consistently resulted in the lowest yield among these three *utera* crops. Crop WUE was higher in lathyrus, while the lowest was observed in linseed. In rainfed lowland rice ecosystems, soil profile contribution, winter rainfall, and nutrient management of utera crops significantly influenced seed yield, ultimately affecting WUE values (Das and Goswami, 2017).

The lentil crop depleted more soil moisture than the lentil and lathyrus. Regarding fertilizer sources, soil moisture depletion was greater by Suphala (NPK 15:15:15) than DAP (NP 18:46). DAP spray had little impact on soil moisture extraction. Soil moisture extraction differentiation was more pronounced at flowering to pod development (6-12 weeks) of *utera* crops. At harvest, the linseed crop recorded a soil moisture content of 17.5% in the top layer (0-15 cm).

3.5 | Production Economics

The economics of *utera* crops- linseed, lentil, and lathyrus-production in terms of gross returns, net returns, and benefit-cost ratio were calculated for different modes of nutrient treatments (Table 7). The lentil crop had the highest net return of ₹ 23024 per hectare with the highest benefit-cost ratio of 2.73, followed by lathyrus. The direct effect of fertilizer management on production economics was more pronounced in Suphala and DAP soil application than in DAP spray. The combined effects of utera crop and fertilizer application were studied; for example, in the case of lentil with DAP (NP 18:46) treatment combination (C_2N_2), the highest gross return of ₹ 40836 was recorded, whereas the lowest gross return of ₹ 14793 was observed under linseed with DAP (NP 18:46) foliar spray treatment combination (C_1N_3). Among the paira crops, the net returns for lentil with DAP (NP 18:46) treatment (C_2N_2) were the highest at ₹ 27,380. Conversely, linseed with DAP (NP 18:46) treatment (C_1N_2) recorded the lowest net return of ₹ 4316. The same treatment combination also recorded the highest benefit-cost ratio of 3.0 in lentil with DAP soil application (C_2N_2). In the case of linseed with DAP (NP 18:46), the benefit-cost ratio was the lowest at 1.36. Availability of nutrients likely enhanced translocation of photosynthates to sinks, leading to improved crop yields and increased income for lentil, along with a higher B:C ratio (Kumar *et al.*, 2023; Saha *et al.*, 2025).

4 | CONCLUSIONS

This study successfully evaluated the performance of three utera crops (lathyrus, lentil, and linseed) under different fertilizer management strategies in the rainfed lowland rice-ecosystem of the Lower Indo-Gangetic Plains. The findings provide valuable insights for sustainable intensification of rice-fallow areas through optimized cropping and nutrient management practices. Among the tested *utera* crops, lathyrus (grass pea) emerged as the most promising option, achieving the highest seed yield of 725 kg ha^{-1}, followed closely by lentil at 721 kg ha^{-1}. Both leguminous crops demonstrated superior adaptation to the rainfed conditions compared to linseed, which yielded only 404 kg ha^{-1}. The excellent performance of lathyrus and lentil can be attributed to their drought tolerance, efficient nitrogen fixation capabilities, and better utilization of residual soil moisture from the preceding rice crop.

The study shows soil application of Suphala (NPK 15:15:15) at 150 kg ha^{-1} yields the highest grain (650 kg ha^{-1}), outperforming DAP soil (634 kg ha^{-1}) and foliar spray (566 kg ha^{-1}). This highlights the importance of balanced nutrients, including potassium, for crop performance under moisture stress. Lathyrus has the best water productivity (5.42 kg ha-mm^{-1}) with the lowest evapotranspiration (133.3 mm), making it ideal for water-scarce areas. Linseed shows poor water efficiency (2.42 kg ha-mm^{-1}) with higher water use (182.0 mm). Economically, lentil with DAP achieves the highest benefit-cost ratio (3.03), offering better profitability despite lathyrus' slightly higher yields.

TABLE 6 Effect of fertilizer management on actual evapo transpiration (Eta) and water use efficiency (WUE) of utera crops in rainfed rice-fallows (mean value of two years)

Treatments	Eta (mm)	Yield (kg ha^{-1})	WUE (kg ha-mm^{-1})
Utera crop			
Linseed	182.0	440	2.42
Lentil	157.4	721	4.58
Lathyrus	133.8	725	5.42
S.Em (±)	-	12.61	-
C.D (p=0.05)	-	37.17	-
Crop Nutrition			
Suphala	156.5	650	4.15
DAP Soil	178.7	634	3.55
DAP Spray	138.1	566	4.10
S.Em (±)	-	15.56	-
C.D (p=0.05)		45.91	-

TABLE 7 Effect of fertilizer management on production economics of *utera* crops in rainfed rice fallows (mean values of 2 years)

Treatments	Cost (₹ ha^{-1})	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	B:C ratio
***Utera* Crops (C)**				
Linseed (C_1)	11320	17151	5831	1.51
Lentil (C_2)	13374	36398	23024	2.73
Lathyrus (C_3)	12571	30223	17652	2.40
Crop Nutrition (N)				
Suphale (N_1)	12807	29536	16728	2.29
DAP Soil (N_2)	12586	28663	16077	2.25
DAP Spray (N_3)	11872	25573	13701	2.10
Interaction effect				
C_1N_1	11756	20249	8493	1.72
C_1N_2	12096	16412	4316	1.36
C_1N_3	10110	14793	4683	1.46
C_2N_1	13706	29841	16135	2.18
C_2N_2	13456	40836	27380	3.03
C_2N_3	12960	38517	25557	2.97
C_3N_1	12206	28742	16536	2.35
C_3N_2	12546	23410	10864	1.87
C_3N_3	10560	20525	9965	1.94

The study recommends cultivating lathyrus with Suphala (NPK 15:15:15) at 150 kg ha^{-1} to maximize yield and water efficiency, and lentil with DAP (NP 18:46) at 125 kg ha^{-1} for better economic returns. Avoid linseed in rainfed utera systems due to poor performance. This research supports the sustainable intensification of rice-fallow areas in the Lower Indo-Gangetic Plains, helping farmers improve land productivity, food security, and income, aligning with the national goal to expand cultivation and promote water- and cost-efficient cropping systems.

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CONFLICT OF INTEREST

The authors have no conflict of interest.

DATA AVAILABILITY STATEMENT

The corresponding author is liable to make the data available on request.

AUTHOR'S CONTRIBUTION

CB: Conducted the experiment as part of an M.Sc. (Ag) research project; SG: Prepared the manuscript write-up; RM: Assisted with soil moisture calculation and graph preparation; SKM: Helped with data recording; SBG: Supervised the work and edited the write-up.

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